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RESEARCH MEMORANDUM

A FLIGHT INVESTIGATION OF THE EFFECT OF FLAP DEFLECTION ON HIGH-SPEED LONGITUDINAL-CONTROL CHARACTERISTICS

By Maurice D. White, Melvin Sadoff,
Lawrence A. Clousing, and
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A FLIGHT INVESTIGATION OF THE EFFECT OF FLAP DEFLECTION ON HIGH-SPEED LONGITUDINAL-CONTROL CHARACTERISTICS

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SUMMARY

Flight tests were conducted on two airplanes, one having a wing of NACA 66-series section and the other having a wing of NACA 230-series section, to investigate the effect of flap deflection on the high-speed longitudinal-control characteristics. The results showed that, as expected, negative deflection of the landing flaps reduced the changes of airplane angle of attack which occur due to compressibility effects at supercritical speeds. It was shown, however, that this did not necessarily improve the high-speed longitudinal-control characteristics. The elevator angle and stick force variations with Mach number were found also to be affected to an appreciable extent by the variation with Mach number of the pitching-moment coefficient of the airplane without tail, downwash at the tail, dynamic pressure at the tail, and aileron floating angle. The manner in which these factors were affected by deflection of the flap was different for the two airplanes. Of the modifications tested on the airplane having a wing of NACA 66-series airfoil section, flaps deflected -6°, and flaps and ailerons deflected -6° and -5°, respectively, the former was more beneficial. Of the modifications tested on the other airplane, flaps deflected -8.7° and flaps deflected $+4^{\circ}$, the latter was more beneficial.

Using currently available wind-tunnel data which, however, were available only for airfoils and wings different from those of the test airplanes, it was not possible to predict whether negatively deflected flaps would improve the high-speed longitudinal-control characteristics of the airplanes.

On one of the airplanes, buffeting severe enough to limit the test range was encountered. Differences in intensity of buffeting between the two airplanes corresponded to differences in the ratios of dynamic pressure at the tail to the free-stream dynamic pressure.

INTRODUCTION

On conventional airplanes with unswept wings, severe diving tendencies have been experienced at supercritical speeds that have been attributed in large part to the increase in angle of attack required to maintain a constant lift coefficient (references 1, 2, and 3).

Analysis of recent wind-tunnel data (reference 4) has shown that upwardly deflected flaps would, by reducing the variation with Mach number of angle of attack for a given airplane lift coefficient, tend to reduce the detrimental effects of compressibility on the high-speed longitudinal-control characteristics of airplanes. On the basis of these results, it was proposed that the landing flaps of conventional airplanes be deflected upward to reduce the angle-of-attack variation at high speeds. For such a modification it was surmised that, since the reduction in angle-of-attack variation results from a loss in effectiveness of the upwardly deflected flaps, further benefit would be obtained from the favorable downwash changes that would occur as a consequence of an inboard shifting of spanwise loading on the wing.

Flight tests have been conducted at the Ames Aeronautical Laboratory on two modern propeller-driven fighter-type airplanes to investigate the utility of this modification. Some of the results of this investigation have been presented in reference 5. In the present report, further results of the investigation are shown and all the results are analyzed. The primary objective of the analysis was to evaluate the relative magnitudes of the factors contributing to the changes in high Mach number longitudinal-control characteristics resulting from the flap deflections. A second objective was to determine by comparison with available wind-tunnel data how accurately the observed changes may be predicted.

In addition, in order to check the assumption that the wing angle-of-attack variation with Mach number was a major source of the diving tendencies on the unmodified airplanes, the data for the unmodified airplanes were analyzed.

SYMBOLS

$C_{m_{A-t}}$ pitching-moment coefficient of airplane less horizontal tail

C_N airplane normal-force coefficient (WA_Z/qS)

$\partial C_{N_t}/\partial \alpha_t$ lift-curve slope of horizontal tail, per degree

A_Z ratio of net aerodynamic force along airplane Z axis (positive when directed upward) to weight of airplane

F elevator stick force (pull force positive), pounds

M free-stream Mach number

S total wing area, square feet

S_t total horizontal-tail area, square feet

W airplane weight, pounds

c chord, feet

$\bar{c}$ mean aerodynamic chord of wing $\left(\frac{\int c^2 dy}{\int c\ dy}\right)$, feet

i_t horizontal-tail incidence, degrees

l_t longitudinal distance from center of gravity to quarter-chord point of mean aerodynamic chord of horizontal tail, feet

q free-stream dynamic pressure, pounds per square foot

q_t/q ratio of impact pressures measured by angle-of-attack heads on horizontal tail and on wing

y	lateral coordinate, feet
α_A	airplane (fuselage reference line) angle of attack, degrees
α_{l_o}	angle of attack for zero lift, degrees
α_t	horizontal tail (chord line) angle of attack, degrees
δ_a	average deflection of both ailerons (down-aileron deflection positive), degrees
δ_e	elevator angle with respect to stabilizer chord line (down-elevator deflection positive), degrees
δ_f	flap deflection (down-flap deflection positive), degrees
ϵ	downwash angle $(\alpha_A - \alpha_t + i_t)$, degrees
τ	elevator effectiveness factor $\left(\frac{\partial C_{N_t}/\partial \delta_e}{\partial C_{N_t}/\partial \alpha_t}\right)$

AIRPLANES

The airplane which had a wing of NACA 66-series airfoil section is designated in this report as airplane 1, and the airplane which had a wing of NACA 230-series airfoil section is designated as airplane 2.

Three-view drawings of airplanes 1 and 2 are shown in figure 1, and three-quarter rear-view photographs of the airplanes are shown in figure 2. General details of the two airplanes are presented in table I.

On both airplanes the wing guns were removed and the gun ports and cartridge-ejection slots were covered with doped fabric. When the flaps were deflected on the airplanes, the gaps between the flaps and the wing on the lower surfaces of both airplanes and on the upper surface of airplane 2 were covered by metal strips. When the flaps of airplane 2 were deflected positively, the gap was covered by a spring-loaded door between the wing and flap on the lower surface.

INSTRUMENT INSTALLATION

Standard NACA continuously recording instruments were used to record the variables measured.

The airspeed heads, a Kollsman type on airplane 2 and an NACA swivelling head type on airplane 1, were mounted in booms one-chord length ahead of the left wing tip of the respective airplanes. No flight calibration was made to determine the position error of the airspeed heads at high Mach numbers. For airplane 1, compressibility corrections for the airspeed head, as obtained from high-speed tunnel tests, were applied.

Airplane angle-of-attack measurements were obtained from directional pitot heads mounted on booms extending one-chord length ahead of the right wing tip of each airplane. Corrections were applied to the readings of this head for compressibility as derived from high-speed wind-tunnel tests of a similar type head. The deflection of the boom or of the wing was believed to be small and was, therefore, not corrected. Similar installations were used for determining the angle of attack of the horizontal tails.

Control-position recorders were connected directly to the elevators and to the ailerons to record the deflections of these surfaces.

TESTS AND PROCEDURE

Flight tests were conducted on airplane 1 with the flaps undeflected, with the flaps deflected -6°, and with the flaps deflected -6° and the ailerons deflected -5°. On airplane 2 flight tests were made with the flaps undeflected, and with the flaps deflected -4.5°, -8.7°, and $+4.0^{\circ}$. For each configuration, data were obtained at Mach numbers ranging from 0.3 to the maximum practicable,

and for normal accelerations ranging from those of steady flight to values corresponding to an airplane normal-force coefficient of about 0.4. Except for one configuration, the test altitudes centered around 20,000 feet with variations not exceeding ±6,000 feet. To reduce the structural loads, the tests of airplane 1 with both flaps and ailerons deflected centered around an altitude of 24,000 feet.

For airplane 1, the center of gravity at take-off was at about 25 percent M.A.C. and moved forward during each flight to about 24 percent M.A.C., due to fuel consumption. The corresponding center-of-gravity movement of airplane 2 was from about 26 percent M.A.C to approximately 25 percent M.A.C. No attempt was made to correct for these small variations in center-of-gravity position in the evaluation of the data.

Normal rated power was used throughout the tests of airplane 2. For airplane 1, normal rated power was used for the dive tests and power required for level flight was employed at lower speeds.

The test procedures were substantially similar for airplanes 1 and 2. The airplanes were trimmed longitudinally at a Mach number of about 0.65 at an altitude of 20,000 feet. For each test Mach number, records were obtained in straight, steady flight or in steady dives. For higher accelerations, essentially static data were obtained in steady turns at constant acceleration or, at the higher speeds, in steady dive pull-outs during which the pilot attempted to hold the acceleration constant while the Mach number was allowed to vary.

In the tests, continuous records were obtained of the airspeed, pressure altitude, normal acceleration, elevator angle, and elevator stick force. In addition, the angles of attack of and dynamic pressures at the wing and the horizontal tail were obtained. These latter quantities were not measured on airplane 2 with the flap deflected -4.5°. Records were also obtained of the motions of the ailerons of the two airplanes.

The precision of the measured quantities is discussed in reference 5.

RESULTS

The primary results obtained in the investigation are shown in figure 3 for airplane 1 and in figure 4 for airplane 2. Some of the

results from reference 5 are repeated here for completeness. Data are shown only for Mach numbers above M = 0.6, data taken at lower Mach numbers showing no important effects of Mach number. Also no results are shown for airplane 2 with the flaps deflected -4.5° because these data were scant and showed no improvement in characteristics.

Figures 3 and 4 show, for each of the configurations tested and for normal-force coefficients of 0.1, 0.2, 0.3, and 0.4 (the last for airplane 2 only), the variation with Mach number of the following variables:

1. Elevator angle, δ_e
2. Elevator stick-force parameter, F/q
3. Airplane angle of attack, α_A
4. Downwash angle at the tail, ϵ
5. Dynamic pressure ratio at the tail, q_t/q
6. Pitching-moment coefficient of the airplane without the tail, $C_{m_{A-t}}$
7. Average aileron angle, δ_a

Items 1, 2, 3, 5, and 7 were evaluated directly from flight measurements; item 4, from the expression $\epsilon = \alpha_A - \alpha_t + 0.5^\circ$; and item 6, from the equation of equilibrium

$$C_m = C_{m_{A-t}} - \frac{\partial C_{N_t}}{\partial \alpha_t} (\alpha_A - \epsilon + \tau\delta_e) \frac{q_t}{q} \frac{S_t}{S} \frac{l_t}{\bar{c}} = 0 \qquad (1)$$

In order to determine the values of $C_{m_{A-t}}$ from equation (1) it was necessary to estimate the values of the factors $\partial C_{N_t}/\partial \alpha_t$ and τ. For airplane 1, these values were determined from tests in the Ames 16-foot high-speed wind-tunnel[1] of a similar tail mounted on an airplane of similar configuration. These data were limited to 0.80 Mach number so that some extrapolation was necessary to cover the range of the present investigation; the variations used are shown in figure 5(a). The variations of $\partial C_{N_t}/\partial \alpha_t$ and τ

[1]These data are on file at Ames Laboratory.

assumed for airplane 2 (fig. 5(b)) follow those obtained in wind-tunnel tests of a horizontal tail of configuration similar to that of the tail of airplane 2.

In the analysis, the values of wing and tail angle of attack, as determined from readings of the single heads mounted ahead of the tips of the respective surfaces, were treated as effective values for the entire surface in evaluating $C_{m_{A-t}}$ from equation (1) and in the ensuing discussion. The values of α_A, ϵ, and $C_{m_{A-t}}$ as obtained by this method are not absolutely correct, but it is considered that the information gained from the use of the data outweighs the objections to their lack of precision. An indication of the validity of the angle-of-attack measurements is given by the results in figures 3 and 4. With few exceptions, the changes in α_A, ϵ, and $C_{m_{A-t}}$ due to changes in airplane configuration and changes in Mach number are qualitatively consistent. One exception to the trend is evidenced by the data for $\delta_f = -6^\circ$ in figure 3. At low Mach numbers, the change in $C_{m_{A-t}}$ resulting from deflection of the flaps alone is indicated to be greater than the change resulting from deflection of both the flaps and ailerons, which is not consistent with anticipated results. Theoretical estimates indicate the error to be in the change in $C_{m_{A-t}}$ for $\delta_f = -6^\circ$. It is deduced from this that sizable changes in wing span load distribution, such as occur when the flaps or ailerons alone are deflected, increase the error in indicated angle of attack at the tail that results from use of a single head. As a consequence, the indicated downwash angles and the indicated values of $C_{m_{A-t}}$ which are derived from these downwash angles are less reliable for these conditions than they are for the case when the wing span load distributions are uniform.

In the tests of airplane 2, buffeting of rather severe degree was experienced, which varied in intensity with flap deflection. The variation with Mach number of the value of A_Z at which buffeting begins is shown in figure 6.

DISCUSSION

In the ensuing discussion the variations of the different parameters that influence the longitudinal-control characteristics at high Mach numbers are analyzed in order to determine how each contributes quantitatively to the observed characteristics. A further step in the analysis is to compare the measured variations of selected parameters with those computed using currently available

wind-tunnel data in order to obtain an idea of the probable accuracy of results from computation of this type.

Generally, longitudinal-balance characteristics are defined in terms of the variation with Mach number of the elevator stick force required for balance, an undesirable diving tendency being described by an increasing pull force with increasing Mach number. It is more convenient here, however, to analyze the results in terms of the elevator angle, using the term "diving tendency" to describe a variation of elevator angle with Mach number such that increasing up-elevator angles are required for balance as the Mach number is increased. The elevator angles are more convenient to use because at high Mach numbers the elevator-effectiveness curves tend to maintain more linear characteristics than do the elevator hinge-moment curves. (See, for example, reference 6.) Comparison of the elevator angle curves and corresponding stick-force parameter curves in figures 3 and 4 shows that, with minor exceptions, the curves have the same shape.

For airplanes of the class tested, the value of C_N for steady flight does not vary greatly from a value of 0.1 through the range of Mach numbers of interest. Accordingly, in the subsequent discussion, the data for $C_N = 0.1$ are interpreted as those for steady, straight flight. The data for higher values of C_N are of interest for stability considerations and for application to airplanes having much higher wing loadings or operating at higher altitudes. These latter data are not discussed at length in the report, however, because they differ only in minor degree from the data for $C_N = 0.1$, and would, therefore, not alter the fundamental conclusions of the investigation.

Unmodified Airplanes

Airplane 1.- The data of figure 3(a) show the expected increase with Mach number of the airplane angle of attack starting at a Mach number of 0.70 and continuing to the highest test Mach number of 0.825. The elevator angle curves of figure 3(a) show that at a Mach number of 0.70 the value of δ_e also starts to vary with Mach number in accord with the variation in angle of attack; that is, increasing up-elevator angles are required for increasing angles of attack. However, at Mach numbers above about 0.76, the trend of the elevator-angle variations does not correspond with the variation in angle of attack, but is opposite in direction. In order to help clarify the reasons for this disparity, figure 7(a) has been prepared, which

compares the changes in recorded elevator angle that occur at Mach numbers above 0.6 with the changes in elevator angle required to balance the variations in α_A, ϵ, and $C_{m_{A-t}}$. It is apparent from this figure that the reversal in trend of the elevator-angle variation starting at a Mach number of 0.76 results from rather abrupt changes in the variations of downwash angle and pitching-moment coefficient of the airplane without the tail.

The observed downwash variations are indicative of a large inboard shift of the wing span loading. A similar shift of span loading has in other instances been attributed to the effect of the fuselage in reducing the severity of the lift loss over the most inboard sections of the wing. It is possible that this effect existed in these tests, but it is believed that the shift in span loading is, in addition, associated with a variation in the aileron angle which is shown in figure 3(a) to occur at the same Mach numbers. The data show an increasing upward deflection or floating of the ailerons as the Mach number is increased above 0.76, which would tend to cause inboard shifting of the span loading. In other flight investigations (reference 7), aileron floating characteristics similar to those shown in figure 3(a) have been identified with separation of the air flow on the upper surface of the wing ahead of the ailerons, which in itself would tend to cause inboard shifts in span loading. There remained then a question as to whether the inboard shift in loading was due primarily to the flow separation or to the aileron deflection resulting from the flow separation. An attempt to resolve this question by comparing the flight results with two-dimensional wind-tunnel data led to inconclusive results; these comparisons are discussed later.

Airplane 2.- The data for airplane 2 in figure 4(a) reveal a general increase with Mach number of the airplane angle of attack similar to that found for airplane 1. Again, however, as shown in figures 4(a) and 7(b), the elevator-angle variations are modified greatly by the variations of other factors, although not to the same degree by the same factors. For example, in contrast with the results for airplane 1, the downwash-angle changes for this airplane are small and are, therefore, of secondary importance through the entire test range of Mach numbers, and on the other hand changes in $\partial C_{N_t}/\partial \alpha_t$, q_t/q and τ, which were relatively minor for airplane 1, appear quite important for airplane 2. A further difference between the two airplanes is in the amount of aileron floating, which was negligible for airplane 2 (fig. 4(a)).

Conclusions from tests of unmodified airplanes.- It is apparent from the foregoing results that, whereas both airplanes

exhibit diving tendencies at high Mach numbers which are attributable in large measure to changes in airplane angle of attack, the effects of changes in other factors are of the same order of magnitude as those due to angle-of-attack changes. It must be concluded from this fact that, whereas reduction of the airplane angle-of-attack variation represents a promising means for reducing diving tendencies, care must be taken to insure that the modifications employed do not simultaneously affect other important variables adversely.

Modified Airplanes

Flaps deflected negatively.- It is shown from a comparison of figure 3(a) with figure 3(b), and of figure 4(a) with figure 4(b) that, for both airplanes when the flaps alone were deflected negatively, the value of α_A was shifted positively at low Mach numbers; whereas at higher Mach numbers the values of α_A approached the values for the undeflected-flap configuration. This indicates that the anticipated loss in flap effectiveness occurred with an attendant straightening of the curves of α_A versus M. In addition, as a consequence of the loss in effectiveness of the deflected flaps there was for both airplanes a greater favorable increase in downwash due to inboard shifting of the spanwise loading and a greater unfavorable decrease in $C_{m_{A-t}}$ with Mach number at high Mach numbers. However, the relative magnitude of these changes was different for the two airplanes. Also, for airplane 2, the values of q_t/q were lower with negatively deflected flaps than they had been with undeflected flaps at the same conditions. As a result of these differences between the two airplanes, the alleviation of the diving tendency due to the negatively deflected flaps was quite pronounced on airplane 1 but hardly discernible on airplane 2.

Flaps and ailerons deflected negatively.- Attempts to obtain further improvements on airplane 1 by deflecting the ailerons and flaps negatively produced the desired additional straightening of the airplane angle-of-attack curves (fig. 3(c)). However, for this case the favorable downwash variations were less than those obtained with the flaps alone deflected. The less favorable downwash variations were due, possibly, to the fact that for these higher aileron deflections the ailerons did not float up as much and they tended to lose effectiveness at the same rate as the flaps did. As a result the spanwise load changes, and consequently the downwash variations, would be reduced. The curves of $C_{m_{A-t}}$ for this configuration

indicate the expected unfavorable variation over part of the Mach number range, followed by a favorable variation at higher Mach numbers. Largely because of the less favorable downwash variation obtained for this configuration, the resultant diving tendencies were greater than were exhibited with flaps alone deflected, so that for airplane 1 the latter configuration is considered the better.

Flaps deflected positively.– For airplane 2, it was reasoned that the failure to attain an improvement in diving tendency by deflecting the flaps negatively (fig. 4(b)) was due to the difference in wing airfoil section as compared with airplane 1. On airplane 2, the peak of the airfoil section loading on the upper surface tends to be more forward than on airplane 1 (cf., figs. 3(d) and 5(d) in reference 8). The increased angle of attack required to maintain a given value of C_N with negatively deflected flaps would produce additional loadings near the leading edge that would decrease the critical Mach number of the upper surface, so that at a given supercritical Mach number there would tend to be a more severe flow separation on the upper surface. The resultant greater lift loss on the upper surface as compared with the condition of flaps undeflected would tend to compensate for the loss of flap effectiveness, thereby reducing the beneficial effects of negatively deflected flaps. This detrimental compensating loss of upper-surface lift would be minimized on airplane 1 where the peak of the airfoil section loading is farther back on the chord.

It was reasoned then that on airplane 2 some improvement in diving tendency might be accomplished by deflecting the flaps positively to provide an upper-surface pressure distribution more closely approximating that of airplane 1 in order to increase the critical speed of the wing. For the flap deflection of 4.0° (fig. 4(c)), to which structural considerations limited these tests, slight improvements in diving tendency were discernible which appear to be attributable to some extent to the reduced variation of airplane angle of attack with Mach number. The variations of ϵ and $C_{m_{A-t}}$ with Mach number were not altered appreciably, but for a given value of C_N and M the values of q_t/q were not reduced as much as for the cases of flaps undeflected and deflected negatively. On the whole, this configuration appeared to give better high-speed longitudinal-control characteristics for this airplane than did either the original configuration or the negatively deflected flaps, although the differences were relatively slight.

Conclusions from tests of modified airplanes.– It is apparent from the foregoing results that although for both airplanes the

negatively deflected flaps effected the desired reduction in variation with Mach number of airplane angle of attack, the additional factors entering into the equation for balance (equation (1)) modified the resultant diving tendencies sufficiently to demonstrate that they would have to be included in any attempts to predict the effects of modifications.

An important factor to be borne in mind when considering the use of negatively deflected flaps is that of tail loads. A sizable change in tail-load coefficient is produced by deflecting the flaps at low Mach numbers as shown by the shift in the curves of $C_{m_{A-t}}$ (figs. 3 and 4). As the flaps lose effectiveness at high Mach numbers, the shift in $C_{m_{A-t}}$ tends to be reduced. While this reduction in $C_{m_{A-t}}$ shift at high Mach numbers is beneficial from the standpoint of reducing tail loads, it is detrimental for reducing diving tendencies. The necessity for compromising on this point may detract greatly from the utility of negatively deflected flaps for a particular airplane.

Comparison of Predicted and Measured Values of Stability Parameters

This comparison is largely confined to two stability parameters α_A and $C_{m_{A-t}}$. The changes in these parameters with Mach number for Mach numbers above 0.6 as predicted using available two-dimensional wind-tunnel data for the basis of the computations are compared with the changes measured in flight.

Unmodified airplanes.- Data from references 8, 9, and 10 were used to predict the characteristics of the unmodified airplanes. The predictions of $\Delta\alpha_A$ and $\Delta C_{m_{A-t}}$ for airplane 1 were made for two cases; aileron angle δ_a constant with Mach number, and δ_a having the same variation with Mach number as occurred in flight. The results are presented in figure 8(a). It may be seen that when the aileron angle is considered to be constant, $\Delta\alpha_A$ for $C_N = 0.1$ and $\Delta C_{m_{A-t}}$ for $C_N = 0.3$ are accurately predicted, but that $\Delta C_{m_{A-t}}$ for $C_N = 0.1$ is not. The results of figure 8(a) also show that, when the aileron angle is considered to vary as occurred in flight, the predicted value of $\Delta C_{m_{A-t}}$ for $C_N = 0.1$ is in fair agreement, but $\Delta C_{m_{A-t}}$ for $C_N = 0.3$ is not. The results for airplane 2 (fig. 8(b)) show discrepancies between flight and predicted variations of $\Delta C_{m_{A-t}}$ and $\Delta\alpha_A$ which are of equal or greater magnitude than those of airplane 1.

Interpreted in terms of the changes in elevator angle required to balance the changes in α_A or in $C_{m_{A-t}}$, the agreement between predicted and actual changes for the two airplanes ranged from 1/2° for the best agreement to 3° for the worst agreement, which is of the order of the entire change in elevator angle experienced. The inconsistent results may be due to errors caused by using two-dimensional airfoil-section data other than that applying to the airplanes concerned and to the inability to compute accurately the interaction of all the factors involved when dealing with a complete airplane. It would appear, however, that the latter is the primary source of error. This thought is supported by the fact that wind-tunnel data for models of other airplanes having wings of the same airfoil section as the test airplanes also showed disagreement with the present flight data of the same degree as existed between flight data and characteristics as predicted from two-dimensional airfoil-section data.

Modified airplanes.- Attempts were also made to correlate the measured effects of flap deflection with predictions based on wind-tunnel data. Because of the lack of data on the actual airfoils of the test airplanes, all available data on both two-dimensional airfoils and on complete wings were considered. These comparisons indicated that while, in general, the trends observed in the flight variations of α_A and $C_{m_{A-t}}$ were verified none of the sources of data provided sufficiently close agreement to be useful. The differences between flight and wind-tunnel values of α_A and $C_{m_{A-t}}$ again were of the order of the entire change with Mach number experienced. It appears, therefore, that unless test data are available over the Mach number range under consideration and for the model of airplane in question, theory and data are at present inadequate to permit an accurate evaluation of whether or not the diving tendencies of an airplane would be reduced by negatively deflected flaps.

Buffeting Considerations

It was noted previously that on airplane 2 severe buffeting occurred which varied in intensity and in point of inception with flap deflection. For the configuration of $\delta_f = -8.7°$, the buffeting was actually severe enough to limit the combinations of C_N and Mach number beyond which the pilot would fly. An indication of the probable major source of the buffeting is given by the

variations with Mach number of values of q_t/q for both airplanes shown in figures 3 and 4. Comparison of the data for airplane 2 (fig. 4) with the buffet boundaries in figure 6 shows that the value of q_t/q at which buffeting begins lies between 0.84 and 0.92 for all flap deflections, which is a relatively narrow range. It appears from this that buffeting of serious proportions begins when the tail becomes slightly immersed in the wing wake. Since, however, the values of q_t/q decrease considerably with only small changes in angle of attack and downwash angle, as the Mach number increases for a particular flap configuration, the situation appears to be more that of the wake expanding to envelope the tail than of the tail moving into a wake of relatively fixed size. The absolute Mach number at which the value of q_t/q starts to decrease will, of course, vary as the wake location relative to the tail is varied by changes in flap configuration. The increasing wing drag that produces the expanding wake undoubtedly reflects unsteady lift conditions over the wing which would also contribute to the observed buffeting. It appears, therefore, that the buffeting observed on airplane 2 is due, in considerable part, to the entry of the tail into the wake, but that the unsteady lift conditions on the wing may also contribute to the buffeting in significant measure.

For airplane 1, the data of figure 3 indicate that the value of q_t/q does not depart appreciably from a value of 1.0 for any of the conditions tested. It appears, therefore, that the small amount of buffeting experienced on this airplane is probably due more to lift changes on the wing than to buffeting on the tail.

CONCLUSIONS

Flight tests have been conducted on two airplanes, one having a wing of NACA 66-series and the other having a wing of NACA 230-series airfoil section, to investigate the effect of flap deflection on the high-speed longitudinal-control characteristics. The following conclusions have been reached:

1. Negative deflection of the flaps had the desired primary effect of reducing the change due to compressibility effects at supercritical speed of airplane angle of attack for steady flight. However, the resultant changes of elevator angle and stick force were greatly modified as well by changes in pitching-moment coefficient of the airplane without the tail, downwash at the tail, dynamic pressure at the tail, and possibly by changes in aileron floating angle, all of which in turn were different for the two airplanes.

2. It was not possible to predict accurately from currently available experimental data, which are available only for airfoil sections and complete wings different from those of the test airplanes, whether negatively deflected flaps would alleviate the diving tendencies obtained on the airplanes.

3. Of the configurations tested on the airplane having a wing of NACA 66-series airfoil section, flaps undeflected, flaps deflected -6°, and flaps and ailerons deflected -6° and -5°, respectively, the most favorable results were obtained with the flaps deflected -6°. Of the configurations tested on the airplane having a wing of NACA 230-series airfoil section, flaps undeflected, flaps deflected -8.7°, and flaps deflected $+4.0^{\circ}$, the most favorable results were obtained with the flaps deflected $+4.0^{\circ}$.

4. There was considerable difference in the buffeting characteristics of the two airplanes at high Mach numbers. On the airplane having a wing of NACA 230-series airfoil section, the buffeting was sufficiently severe, particularly for negative flap deflection, to limit the Mach numbers and accelerations to which the tests could be carried, while for the other airplane the buffeting was mild. The differences in the intensity of buffeting corresponded to the differences in the ratios of dynamic pressure at the tail to the free-stream dynamic pressure for the two airplanes.

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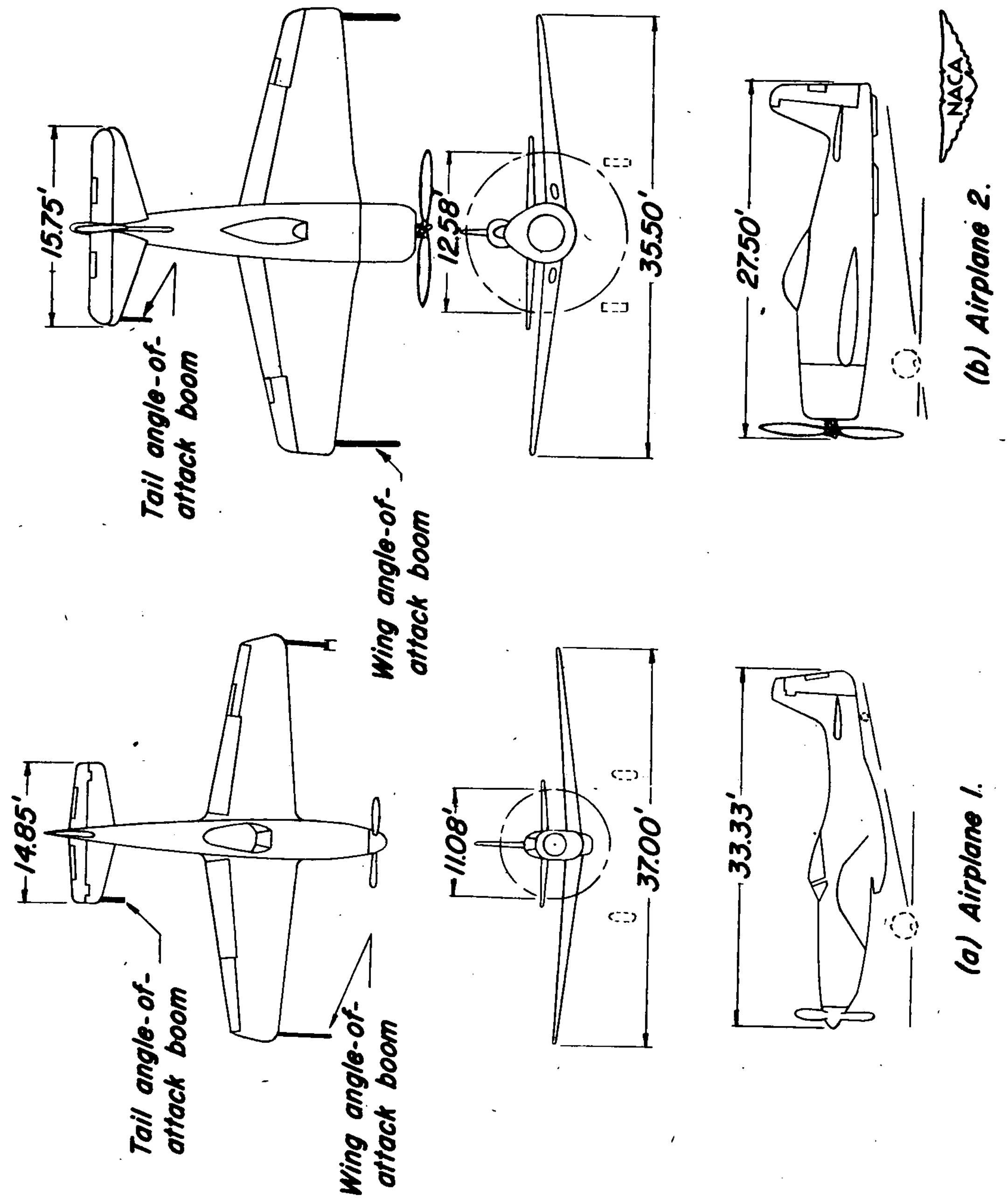
TABLE I.– GENERAL SPECIFICATIONS OF THE TEST AIRPLANES

Item	Airplane 1	Airplane 2
Gross weight, pounds (average during flight)	8200	9100
Wing		
Area, square feet.............	235	244
Span, feet	37.0	35.5
Aspect ratio	5.82	5.17
Airfoil section		
Root, at airplane center line	NACA 66,2–(1.8)(15.5)	NACA 23018
Tip	NACA 66,1–(1.8)(12)	NACA 23009
M.A.C., inches	80.17	87.55
Incidence (root chord to fuselage reference line) ...	1.0°	–1.5°
Twist........................	–2.5°	0°
Wing flaps, each		
Type	Plain	Slotted
Span, feet	9.5	9.65
Tip location, percent semi-span.........................	60	65
Chord, percent local wing chord	22	23
Ailerons, each		
Type balance	Internal sealed	Frise with spring tab
Span, feet	6.85	6.43
Chord, percent local chord		
Inboard end................	18.9	24.2
Outboard end...............	17.7	24.2
Horizontal tail		
Area, (including section through fuselage), square feet........................	48.4	52.2
Span, feet	14.85	15.75
Aspect ratio	4.55	4.75
Airfoil section		
Root.......................	NACA 65_1–012	NACA 0013
Tip	NACA 65_1–010	NACA 0012
Incidence (root chord to fuselage reference line), degrees	0.50	0.50
Elevator area, square feet.......	12.85	18.63

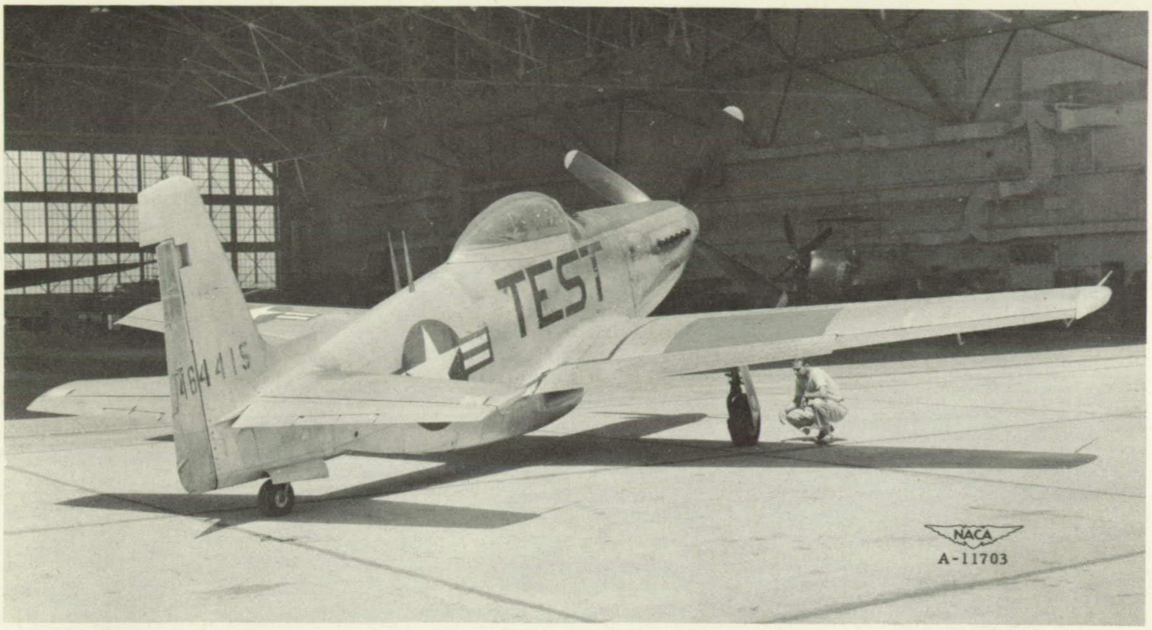
NACA



(a) Airplane 1.

(b) Airplane 2.

Figure 1.- Three-view drawings of airplanes tested.



(a) Airplane 1.

(b) Airplane 2.

Figure 2.- Three-quarter rear views of airplanes tested.

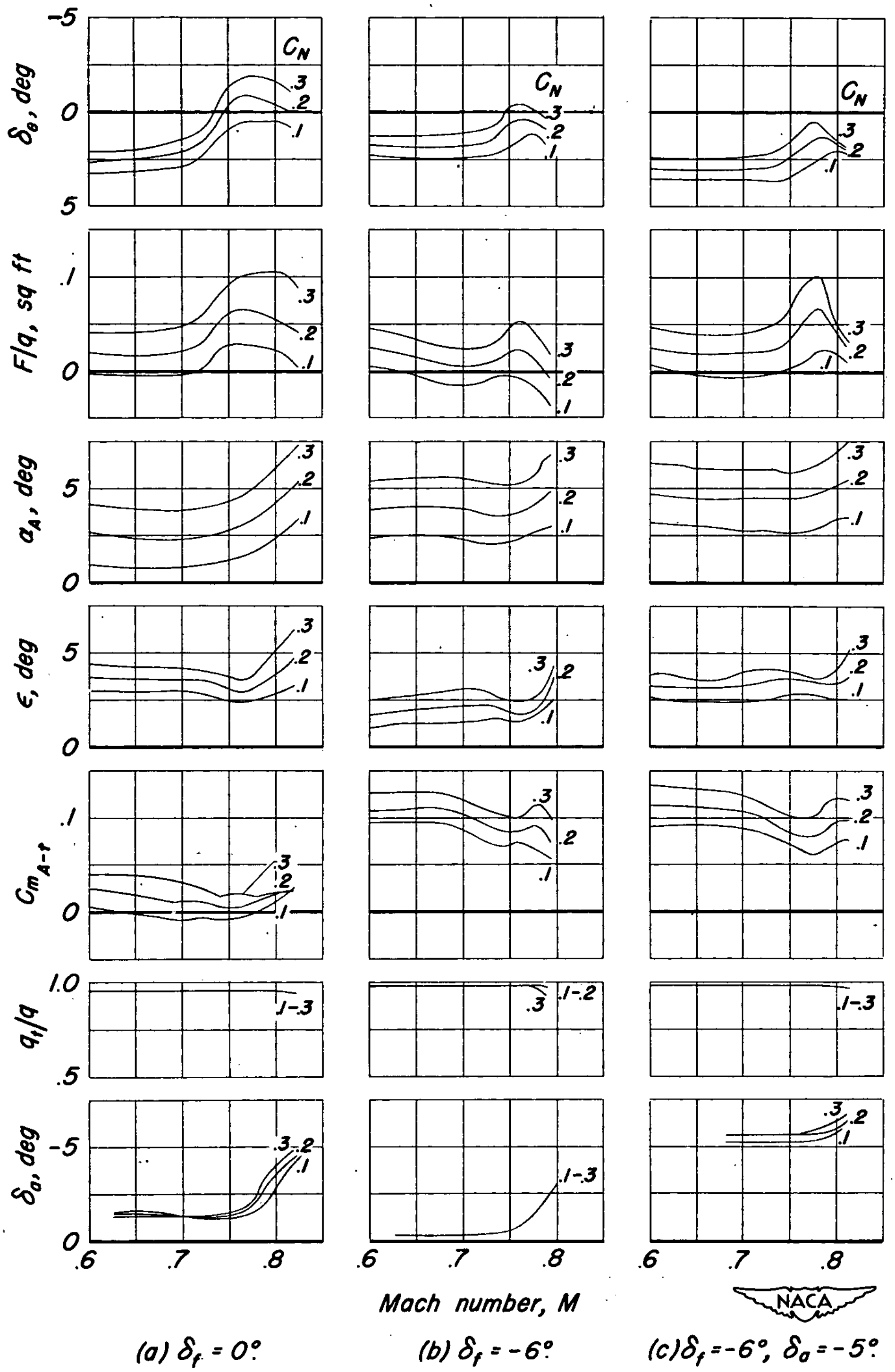


Figure 3.- Longitudinal-control characteristics of airplane I with several modifications.

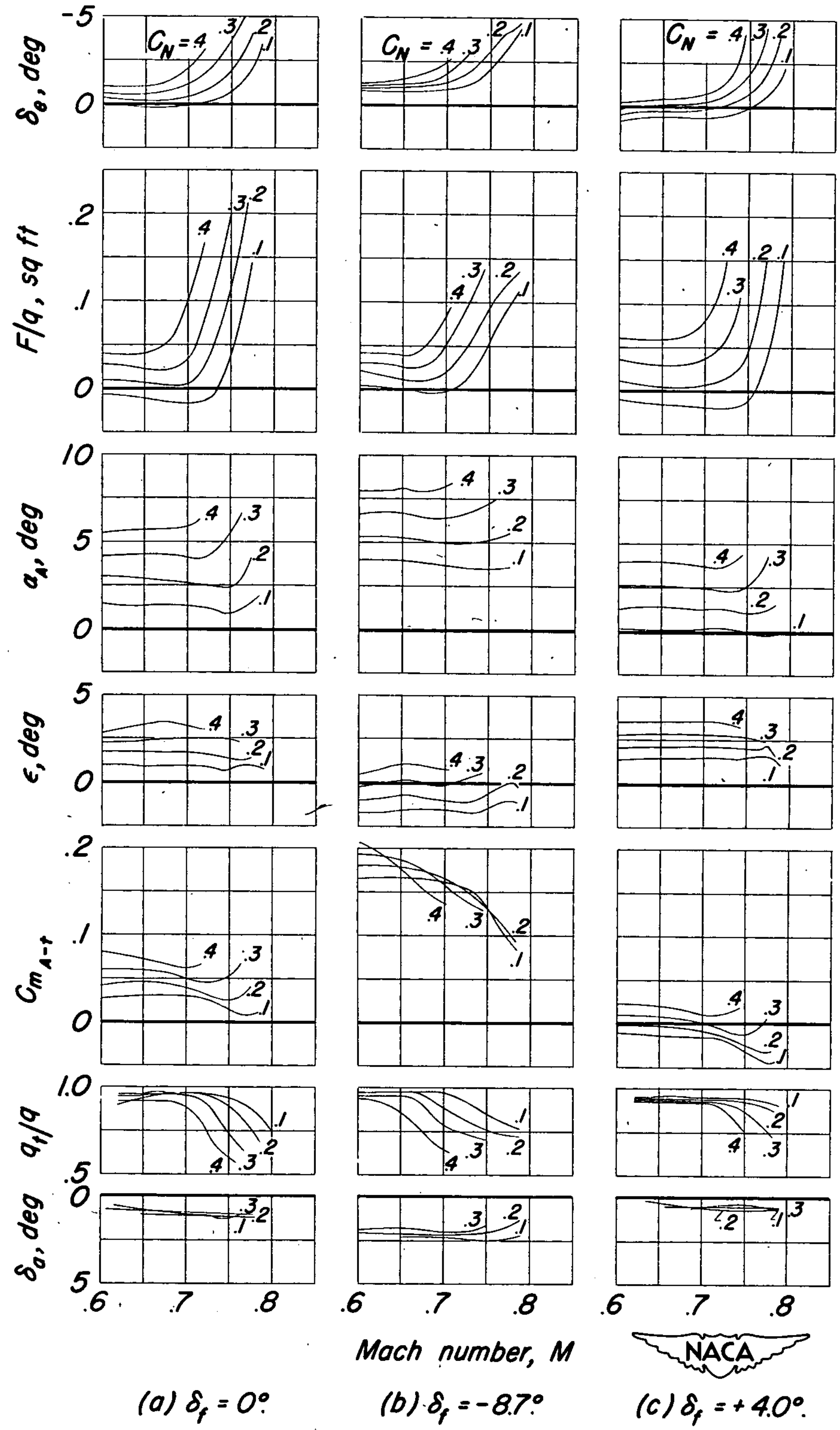


Figure 4.- Longitudinal-control characteristics of airplane 2 for several flap deflections.

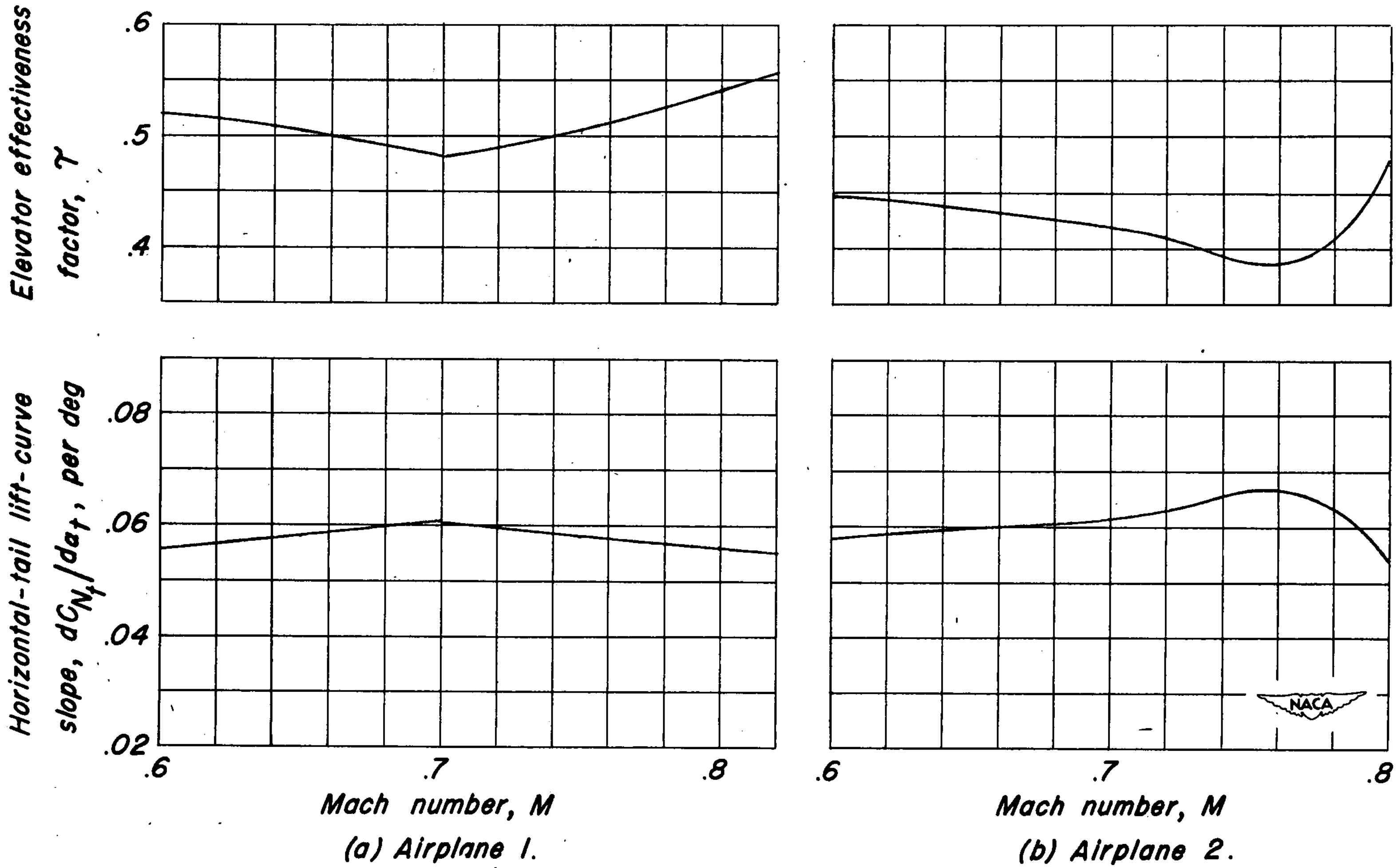


Figure 5.– Variations with Mach number of values of the horizontal-tail lift-curve slope, $dC_{N_t}/d\alpha_t$, and elevator effectiveness factor, τ, assumed in analysis.

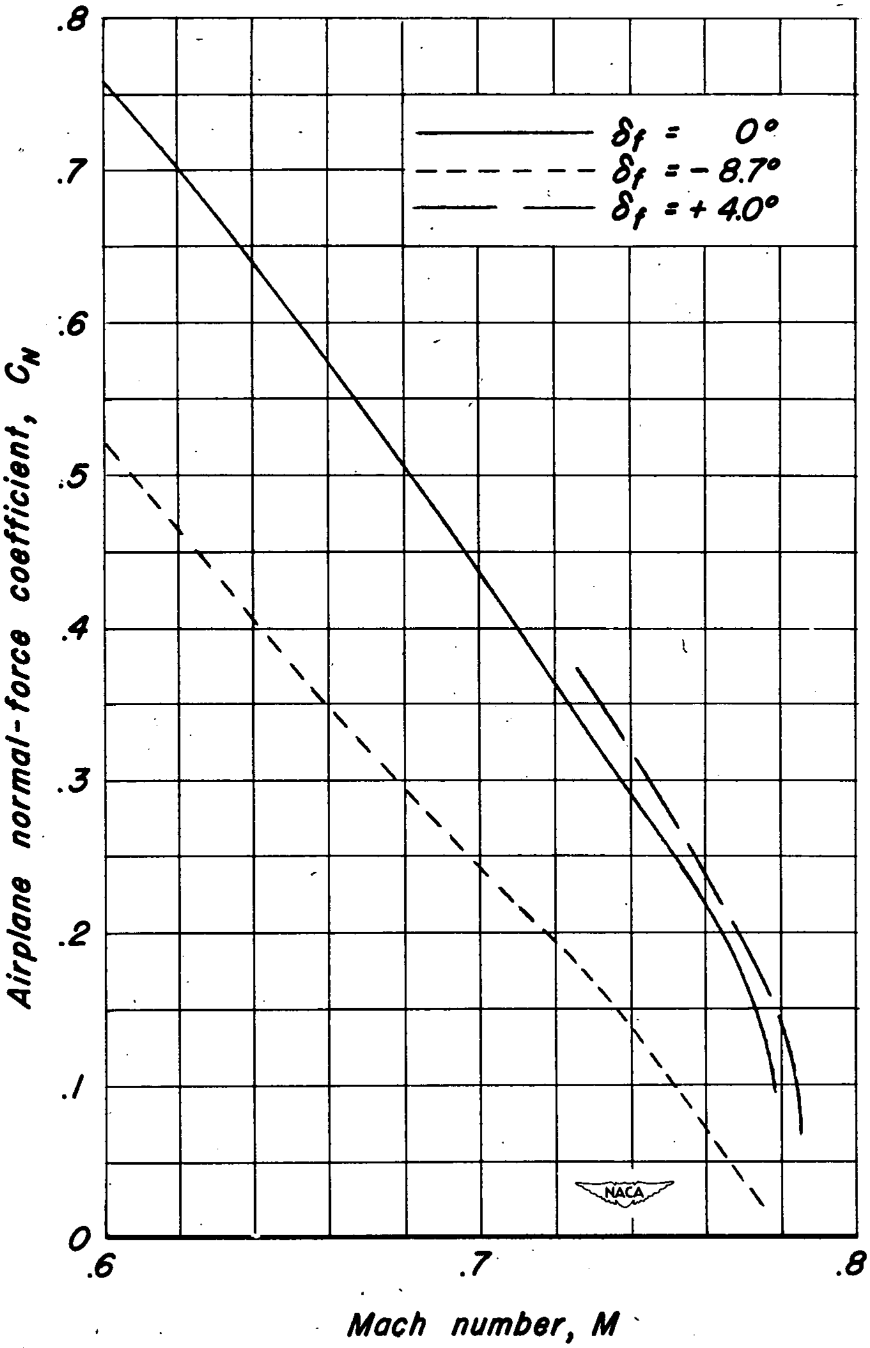
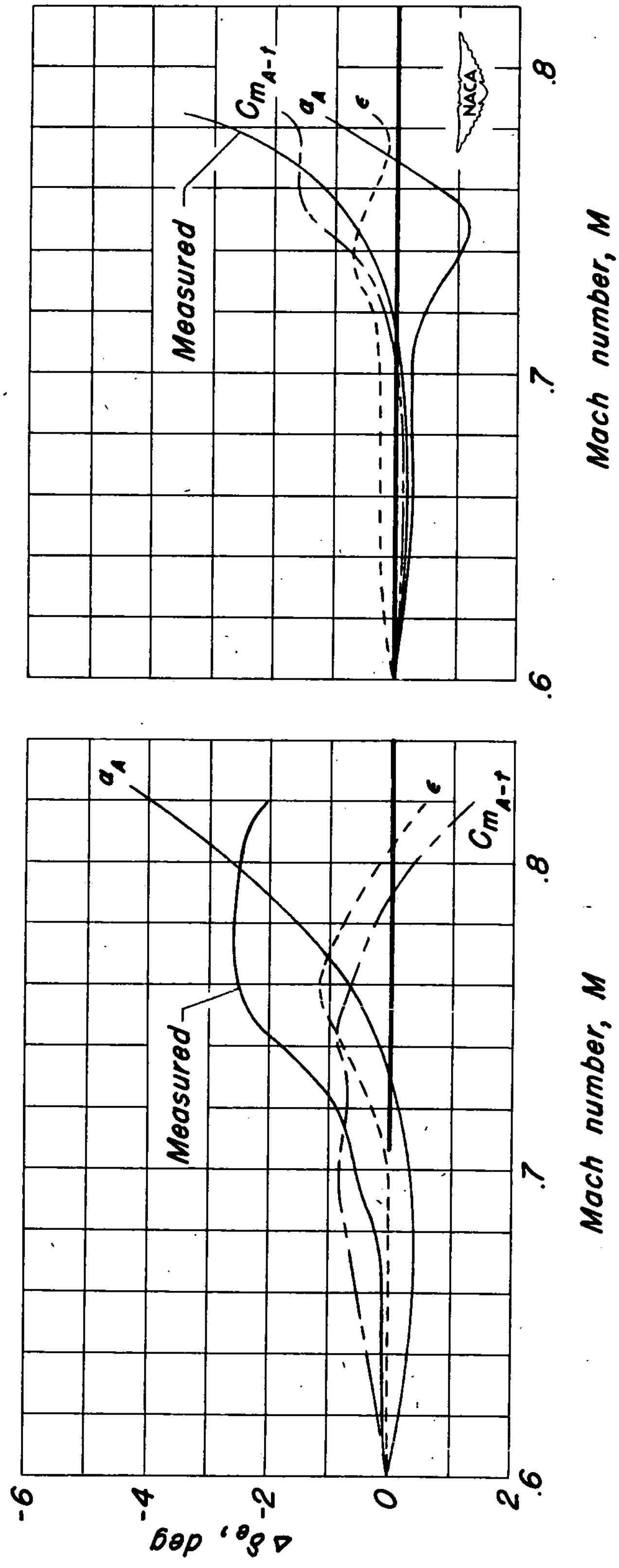


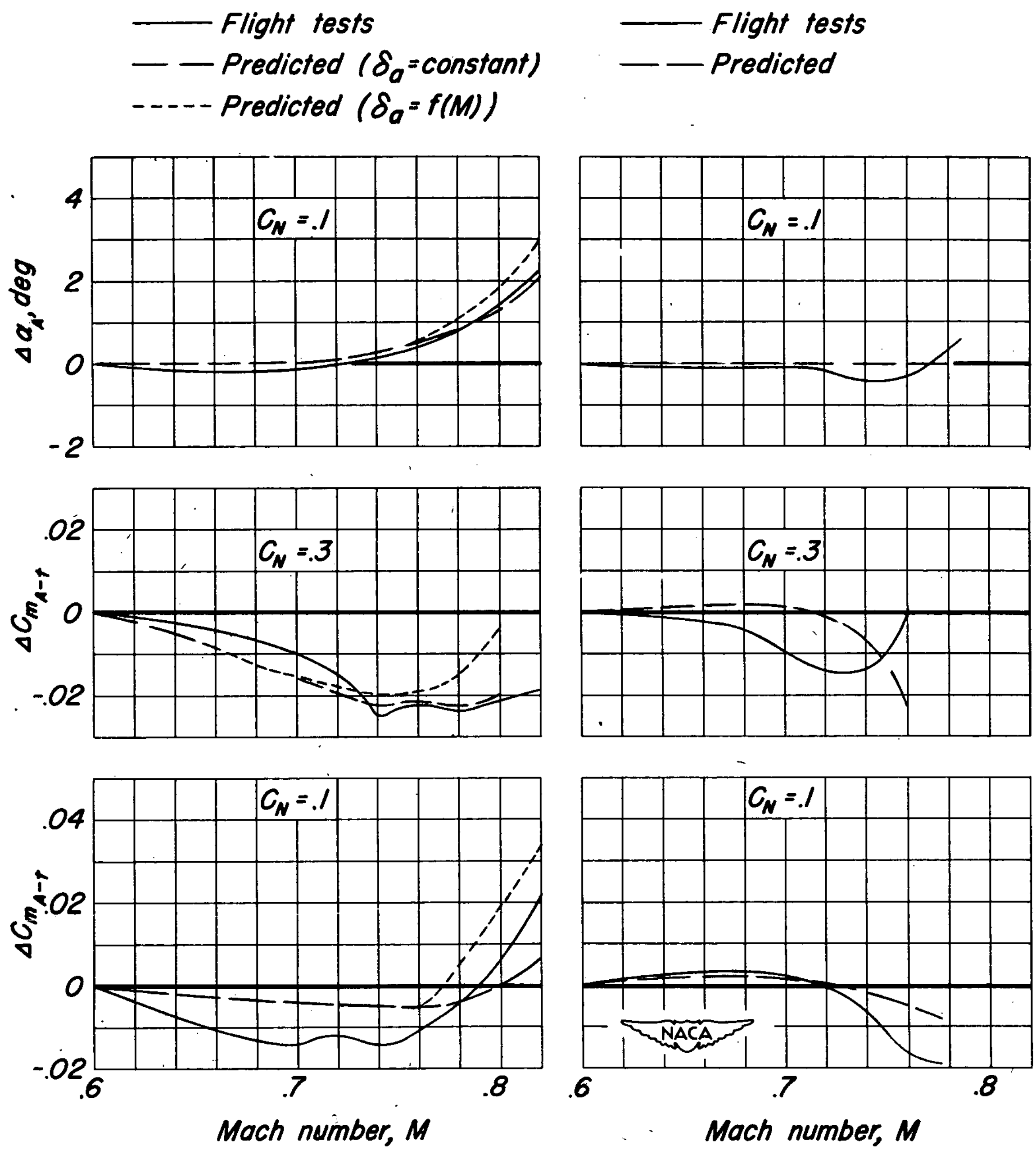
Figure 6.– Variation with Mach number of value of C_N at which buffeting occurred. Airplane 2.



(a) Airplane 1.

(b) Airplane 2.

Figure 7.- Comparison of measured elevator angle changes with the changes in elevator angle required to balance the pitching moments resulting from changes in α_A, ϵ, and $C_{m_{A-t}}$. $\delta_f = 0°$, $C_N = 0.1$.



(a) Airplane 1. (b) Airplane 2.

Figure 8.- Comparison of the changes in α_A and $C_{m_{A-t}}$ as determined from flight tests and as determined from two-dimensional wind-tunnel data. $\delta_f = 0°$.